Comparison of Analogue Model and Field Station Results for the Newfoundland Region

Dave HEBERT**, J. A. WRIGHT, H. W. DOSSO, and W. NIENABER

1Department of Physics, University of Victoria, Victoria, B.C., Canada
2Department of Earth Sciences, Memorial University of Newfoundland, St. John’s, Newfoundland Canada

(Received August 15, 1983)

A comparison of induction arrows calculated from analogue model and field station measurements is reported for fifteen locations in the Newfoundland region of Atlantic Canada. The comparison is made at four periods 100s, 300s, 900s, and 1800s. The differences between the total induction response as represented by the field results and part of the induction response due to the conductive ocean alone as represented by the model results are presented in the form of difference induction arrows. These difference arrows are representative of the anomalous conductivity associated with the tectonic features of the region. The major tectonic structures identified as contributing to the anomalous response in Newfoundland are the Carboniferous sedimentary basins both onshore and in the Gulf of St. Lawrence and a conductive feature in eastern Newfoundland probably associated with the ancient margin of the proto-Atlantic Iapetus Ocean. There is also a suggestion that the crustal conductive zone underlying the Nova Scotian Shelf extends to the Grand Banks off Newfoundland.

1. Introduction

The Newfoundland region, on the east coast of Canada, has been of great interest to many geophysicists as it contains an ancient plate margin marking the closure of the proto-Atlantic (Iapetus) Ocean. Newfoundland is an island with a strong coast effect that could obscure any anomalous fields produced by the ancient plate margin.

An analogue model of the Newfoundland region was constructed to determine the scope of the coast effect in the region (HEBERT et al., 1983). Graphite foil and plate are used to represent the integrated conductivity of ocean and sediments, while brine represents land. A simplified map showing the bathymetry on which the analogue model is based is shown in Fig. 1. HEBERT et al. (1983)

**Now at Department of Oceanography, Dalhousie University, Halifax, N.S. Canada

673
have described the behavior of the magnetic field and induction arrows over the model for four simulated periods (100s, 300s, 900s, and 1800s).

Field station results in the Newfoundland region are taken from the results of HYNDMAN and COCHRANE (1971), BAILEY et al. (1974), COCHRANE and WRIGHT (1977), and Wright (unpublished data). The location and source of results for each of the fifteen field stations in the region studied are shown in Table 1. The induction arrows calculated at these stations are compared to model single station induction arrows for the same location.

The geology of Newfoundland and the contiguous marine area is described by WILLIAMS (1979). The region represents the northernmost exposure of the Appalachian Orogen and its tectonics are described within this setting. Figure 2 shows the location of the field stations and the major tectonic divisions within the island. The development of the orogen is explained using plate tectonics in terms of the opening and subsequent closing of the Iapetus (proto-Atlantic) Ocean.
Comparison of Analogue Model and Field Station Results

Table 1. Location and source of each field station.

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonavista</td>
<td>48°43'N</td>
<td>53°06'W</td>
<td>A</td>
</tr>
<tr>
<td>Cape North</td>
<td>46°53'N</td>
<td>60°30'W</td>
<td>B</td>
</tr>
<tr>
<td>Deer Lake</td>
<td>49°12'N</td>
<td>57°17'W</td>
<td>C</td>
</tr>
<tr>
<td>Exploits</td>
<td>48°52'N</td>
<td>56°18'W</td>
<td>A</td>
</tr>
<tr>
<td>Flowers Cove</td>
<td>51°18'N</td>
<td>56°43'W</td>
<td>D</td>
</tr>
<tr>
<td>Green Point</td>
<td>49°40'N</td>
<td>57°56'W</td>
<td>D</td>
</tr>
<tr>
<td>Little Hearts Ease</td>
<td>48°01'N</td>
<td>53°42'W</td>
<td>A</td>
</tr>
<tr>
<td>Marystown</td>
<td>47°10'N</td>
<td>55°10'W</td>
<td>A</td>
</tr>
<tr>
<td>New World Island</td>
<td>49°29'N</td>
<td>54°30'W</td>
<td>A</td>
</tr>
<tr>
<td>Northwest Gander</td>
<td>48°27'N</td>
<td>55°27'W</td>
<td>D</td>
</tr>
<tr>
<td>Serpentine Lake</td>
<td>48°55'N</td>
<td>58°11'W</td>
<td>D</td>
</tr>
<tr>
<td>Stephenville</td>
<td>48°20'N</td>
<td>58°20'W</td>
<td>B</td>
</tr>
<tr>
<td>St. John's</td>
<td>47°35'N</td>
<td>52°40'W</td>
<td>A</td>
</tr>
<tr>
<td>Trepassey</td>
<td>46°43'N</td>
<td>53°24'W</td>
<td>A</td>
</tr>
<tr>
<td>Whalehead (WH)</td>
<td>50°42'N</td>
<td>59°20'W</td>
<td>C</td>
</tr>
</tbody>
</table>


(Wilson, 1966). The Humber zone represents the ancient continental margin of North America. The Dunnage zone is the vestige of the Iapetus and is composed mainly of mafic volcanic rocks and associated marine sediments. The Gander zone marks the eastern margin of the proto-Atlantic and consists of units representative of those found in convergent plate margins today. Based mainly on geochemical argument, Strong et al. (1974) suggest that there was an eastward dipping subduction zone beneath the Gander margin. The presence of a geomagnetic anomaly in this region (Wright and Cochrane, 1980) is generally supportive of this suggestion. Finally, the easternmost Avalon Zone is associated with the ancient continental margin on the eastern side of the Iapetus. It consists mainly of late Precambrian volcanic and sedimentary rocks.

The results of the analogue model and the field data are discussed for the fifteen stations in relation to the major tectonic boundaries, as well as the ocean effect near each site. The tectonic boundaries between the subdivisions are as follows (Williams, 1979). The major fault zone separating the Humber and Dunnage zones is known as the Baie Verte-Brompton Line or the Cabot Fault. To the east, the division between the Dunnage and Gander zones is marked by a linear trend of ultramafic outcrops known as the Gander River Ultrabasic Belt. The Dover Fault represents the easternmost division between the Gander and Avalon zones.
2. Difference Induction Arrows

The comparison of the model results and actual field results can be accomplished in many ways; some quantitative and some qualitative. This paper treats single station transfer functions as opposed to contoured values as would arise from magnetometer array studies and it seems appropriate therefore to compare the transfer functions (or induction arrows) on a station by station basis. In order to make the comparison more quantitative, a difference induction arrow is calculated as the vector difference between the model and field data. According to Wolf (1982), for weakly coupled conductors (most geophysical cases), the fields can be added linearly. The calculation of difference arrows is based on the linearity of the transfer function relations written for both E and H polarization (using $E$ and $H$ superscripts) as

\begin{align}
B_x^E &= a B_x^E + b B_y^E, \\
B_y^E &= a B_y^E + b B_x^E.
\end{align}
Subscripts \(z\), \(y\) and \(x\) refer respectively to the vertical and orthogonal horizontal components. If the anomalous magnetic field (assumed to be \(B\)) produced jointly by the coast effect and a crustal feature (say fault zone) can be separated, it is easily seen that the total induction arrow is the vector sum of the induction arrows for both structures. The essential assumption is that the mutual inductance between the two anomalous conductors can be neglected with respect to the self induction by the source field in the bodies individually. Preliminary results by Weaver and McKirdy (private communication, 1982) for simple three-dimensional models using the thin sheet approximation show that the direction of the difference arrows agrees with the direction of induction arrows for the appropriate structure. There is disagreement in the magnitude of the arrows, possibly due to including the normal field in the calculation of the induction arrows. Further detailed work will be needed to determine the limits of the conditions for validity of difference arrows. Induction arrows using only anomalous fields would be preferable to single station or inter-station induction arrows for this separation.

3. Discussion

The induction arrows, specifically the difference arrows, are discussed for each station. It is apparent from Fig. 2 that the stations are divided into two groups: group I those close to one of the major tectonic divisions (SL, SV, DL, EXP, NWI, NWG, BNV, LHE) and group II those relatively more distant from the tectonic divisions (WH, FLC, GP, CN, MTN, TRE, STJ). The field results for all of the stations show generally low and highly scattered values for the quadrature arrows. The quadrature arrows for the model results are influenced primarily by inductive rather than conductive effects. The inductive effects are more difficult to model because of the physical size constraint placed on the model construction. For these reasons, it is felt that the difference quadrature arrows should only be interpreted with considerable caution and they are not discussed further in this paper.

3.1 Stations located near fault zones

If the fault zones and deep structures associated with them represent conductive anomalies, then this will be manifested by a significant difference arrow. At a period of 100s, the in-phase induction arrows (Fig. 3) for all the stations in group I show large differences both in direction and amplitude between the model and field results. The difference arrows for the in-phase response are shown in Fig. 4. The model induction arrows have larger amplitudes than the field values and point towards the nearest shallow water as expected, since the coast effect is the only possible model anomaly (HEBERT et al., 1983). The field arrows are generally turned to point inland to some extent. For Deer Lake, Serpentine Lake and Stephenville these effects may be attributable to the Cabot Fault
and the locally prevalent Carboniferous sedimentary basins in this region. At Exploits, New World Island, North West Gander, Bonavista and Little Heart’s Ease, the field results are highly attenuated with respect to the model results. This is not expected, especially for the inland stations of NWG and EXP and is an expression of the conductivity anomaly associated with the Gander zone discussed by Wright and Cochrane (1980). This anomaly shows clearly in the difference arrow presentation (Fig. 4).
At 300s, the agreement between the model and field results for all stations is closer than for 100s. Except for LHE, NWI, and BNV the difference arrows (Fig. 4) are small and not significant. There is still a small anomalous effect at DL, SL and SV associated with the sedimentary basins in western Newfoundland. The significant difference arrows for stations near the Gander zone boundary are again an expression of the conductivity anomaly pertaining to this zone.
At 900s, the results for all of these stations indicate that the field arrows are larger than the model arrows. There is little indication of the Gander zone anomaly as is expected from a two-dimensional model study of the anomalous conductor (WRIGHT and COCHRANE, 1980). For the stations to the west, the difference arrow points towards the Cabot Strait and Gulf of St. Lawrence. This is indicative that the model depth may not have fully taken into account the thick offshore sedimentary section in the Gulf.

The results at 1800s show that the difference arrows are small for all stations and are probably not significant. The local conductive features discussed above have no appreciable response at this period. One interesting result common to most of the stations is that the field arrows are larger than the model arrows particularly at NWG. This could be an indication of source effect in the z component of the field variations. An alternative explanation is that the conductive zone in the crust proposed by COCHRANE and HYNDMAN (1974) for the Nova Scotian Shelf might extend to the north under the Grand Banks and be causing an enhancement of the arrows for land based stations in Newfoundland. This latter hypothesis can only be tested with an ocean bottom magnetometer operating near the edge of the Grand Banks.

3.2 Stations located away from the tectonic boundaries

The stations Whalehead, Flower’s Cove, Green Point, Cape North, Marystown, Trepassey and St. John’s are all stations located immediately on the coast and relatively distant from the major tectonic boundaries. It is expected that if the bathymetry and offshore sedimentary sections have been represented correctly in the laboratory model, the model and field results should show close correspondence with small difference arrows. If the differences between the analogue model and the actual bathymetry and geology of the region are strictly in the depth and thickness of the sequences rather than in actual spatial variation, it is anticipated that the model and field arrows will be colinear but of different magnitudes depending on whether the model underrepresents or overrepresents the integrated conductivity.

At 100s period, the stations Flower’s Cove, Cape North and Green Point adjacent to the Gulf of St. Lawrence and Cabot Strait all show model and field arrows that are essentially coincident with the model arrow larger in all cases (Fig.3.). This suggests that there are no local or regional anomalous conductors and that the model conductivity in the Gulf of St. Lawrence is too large. At Whalehead there is a significant difference arrow. As the model arrow points towards the nearest ocean and the field arrow is oblique to it, the difference arrow cannot be explained in terms of improper modelling of the Gulf. Instead, there must be some geological feature in the vicinity of the station that is the source of the anomalous difference arrow. There is no indication of a major boundary onshore near Whalehead and the tectonic feature responsible may be a submarine feature in the Gulf (e.g. a resistive feature). For the stations in the Avalon zone (Marystown, Trepassey and St. John’s) the model and field
arrows are again almost coincident, though of different magnitudes (Fig. 3.). For the model results, the ocean depth (including the integrated conductivity of the offshore sediments) is probably overestimated, thereby giving rise to the larger model arrows. The coincidence of the arrows indicates that the coast effect is the dominant effect at these stations.

At 300s, the model and field results at all of these stations show excellent agreement both in amplitude and direction. This is further confirmation that the results at these stations are dominated by coast effect and that the slight mismatches in amplitude at 100s for these stations are most likely an artifact of the model construction. The good agreement for the arrows at Whalehead indicates that the perturbing structure near this station, postulated on the basis of the results at 100s, must only be a local structure not influencing the results at longer periods.

At 900s, the model arrows for the stations surrounding the Gulf (Flower's Cove, Whalehead and Green Point) are very small, while the field results at Flower's Cove and Green Point continue to show a moderate shallow water coast effect (Fig. 3.). This could be the result of a current flow at depth under the Gulf as suggested by Bailey et al. (1974). The stations Trepassey and St. John's show very good agreement both in amplitude and direction. At Marysville, the field arrow is larger and points more southerly than the model arrow. If the crustal conductor proposed under the Nova Scotian shelf (Cochrane and Hyndman, 1974) extends either to the northern end of the Nova Scotian shelf or to the southern Grand Banks, this is the effect that we would expect to see.

The results for 1800s give small and scattered difference arrows for the stations around the Gulf of St. Lawrence but show excellent agreement in direction and magnitude for Trepassey and St. John's. Both the stations Cape North and Marysville give field arrows in the same direction, but of different magnitude than the model results. For this long a period, the finite extent of the deep ocean modelled becomes a concern and it is likely that the amplitudes of the model results have been affected.

4. Summary

The comparison of the single station transfer functions for field results and those for a scaled analogue model for the Newfoundland region show that the field results can be interpreted to the first order in terms of the coast effect and the effects of the major tectonic features associated with the Appalachian Orogen in Newfoundland. The results are expressed in terms of a difference induction arrow used to represent the portion of the field arrow that is not attributable to the coast effect alone. The field results viewed in this way show that the Carboniferous sedimentary basins in western Newfoundland and offshore in the Gulf of St. Lawrence have a significant effect on the transfer functions at periods of 100s and 300s. The conductive feature proposed by Wright and Cochrane (1980) to be associated with the Gander zone in eastern New-
foundland is clearly seen in the difference arrows for stations near the Gander zone at periods of 100s and 300s. There is a suggestion that many of the stations may be influenced at periods of 900s and 1800s by a conductive feature to the south of the island of Newfoundland. This conductor might be related to that proposed by Cochrane and Hyndman (1974) for the Nova Scotian shelf. Perhaps the most striking result of the work is the high correspondence between the model results that take into account only the sea-water and shallow sediments effects and the field observations. This establishes beyond doubt the validity and usefulness of the analogue model technique in interpreting transfer functions in regions of complicated coastal geometry and complex tectonics.

The authors wish to acknowledge the following financial support: An NSERC Graduate Fellowship (DH) and NSERC research grants to HWD and JAW. We benefitted from useful discussions with R.C. Bailey, University of Toronto and J.A. Greenhouse, University of Waterloo concerning the concept of difference induction arrows. We thank D. Wolf for making available a preprint of his paper.

REFERENCES


Wilson, J. T., Did the Atlantic close and then reopen? Nature, 211, 676–681, 1966.


Wolf, D., Inductive coupling between idealized conductors and its significance for the geomagnetic coast effect, J. Geophys., 1982 (submitted for publication).